PUBLICATIONS

OF THE

Astronomical Society of the Pacific.

VOL. XXIII   SAN FRANCISCO, CALIFORNIA, DECEMBER, 1911   NO. 139

HEATING THE ATMOSPHERE.

By ALEXANDER G. MCADIE.

Sitting by an open fire, watching the coals burn, the thought may come that we are indeed burning ancient starshine. For the Sun is of course a star, and, fortunately for us, the only star near enough to present a face for study. The next nearest Sun is three hundred thousand times as far away, or, in astronomical units, four light years. Therefore, we need not concern ourselves much about the amount of stellar energy other than solar intercepted by the Earth and stored as fuel.

Now, the solar radiation does not fall directly upon the Earth's surface, which as will appear later, is also most fortunate for us; but falls upon a thin gaseous envelope and passes through this to the Earth. Some of the solar energy is absorbed by the atmosphere, and for different rays the atmosphere has different rates of absorption. Some of the energy is reflected back into space. In fact, the albedo or reflection may be as much as 33 per cent. And, finally, some of the energy, especially some of the short waves, may undergo transformation in the higher levels, possibly through ionization. The chief absorbing medium in the lower air is water vapor, particularly effective with the long waves.

ABBOT, FOWLE, and ALDRICH, in various reports of the work carried on at the Astrophysical Observatory, have fixed the average value of the solar constant of radiation at 1.925 calories per square centimeter per minute for the epoch 1905-1909. Higher values are to be expected during the sunspot minimum. For a sunspot cycle, 11.1 years, the average value may be taken as 1.95 calories.

In 1909 Abbot, using a spectro-bolometer on the summit of Mount Whitney (14,502 feet), determined the energy distribution in the solar spectrum outside the atmosphere as lying between wave-lengths 0.29 μ in the ultra-violet and 3.0 μ in the infra-red.

The average temperature of the Earth is 287° A. (Absolute) and that of the upper atmosphere approximately 220° A. The apparent temperature of the Sun, computed by various methods, ranges from 5840° A. to 6430° A.

If there were no atmosphere the Earth would receive heat during the day at a rapid rate and lose it rapidly during the night. Life in its present form would not be possible. But the atmosphere, and, as we shall see further on, the water vapor in particular, maintain conditions as we now know them.

In discussing the effect of the isothermal layer upon the temperature of the Earth and lower atmosphere, Humphreys[1] shows that if this outer atmospheric shell lets in heat more rapidly than it lets it out, the inclosed object—the Earth—will become warmer. Assuming that the Earth radiates as a black body, the sum of the incident and reflected energy passing through the outer layer is approximately 4/3 of that originally incident, and the radiant energy received by the Earth will be about 11 per cent greater than if there were no absorptive layer. The surface of the Earth is therefore some 7° C. warmer than it would be without this absorbing layer. But this is a general statement, and, in fact, owing to the alternation of day and night, and changes due to the Earth's motion in its orbit, the changing angle of incidence of the solar rays, and, above all, the varying distribution of water vapor over the Earth, it is a difficult matter to estimate accurately the incoming and outgoing energy.

In the atmosphere itself the heat is not uniformly distributed, for as clouds form, the latent heat of condensation may cause peculiar temperature inversions; and, conversely, as the clouds become invisible, the latent heat of vaporization may cause an inversion of temperature. Furthermore, there are various convectional gains and losses. The diurnal vertical convection is confined chiefly to the layers below 5,000 meters; but there

[1] *Bulletin Mt. Weather Observatory*, Vol. II, part 5, page 288.

are certain cyclonic circulations in which the convection extends to higher levels.

If the solar constant were constant, the Earth would receive in a year something over one hundred million million million[1] calories. In popular terms, this is sufficient heat to melt a layer of ice 33 meters (100 feet) annually or to evaporate 1.66×10^{13} kilograms of water. This, then, is what the surface of the Earth would receive if there was no atmosphere.

On the other hand, the surface receives heat from the interior and a rough estimate of the amount may be obtained by multiplying the temperature gradient in the soil—1° C. for 35 meters—by the average thermal conductivity, which is .006 gram calories per square centimeter per second. According to ABBE and VON HERRMANN, the amount in a year is 54 calories per square centimeter or sufficient to melt a layer of ice 7 millimeters thick (.28 inch). The total amount will be $54 \times 2 \times 13.14 \times 6{,}370{,}191 \times 6{,}370{,}191$ calories.

From above and below, then, the atmosphere receives heat. The volume of the atmosphere is in cubic meters $4{,}080 \times 10^{15}$. Multiplying by the weight of a cubic meter of air under normal conditions—1.293 kilograms—we have for the weight of atmosphere 5.3×10^{18} kilograms, or, in English measure, something like 5,800 million million tons. The mass of the atmosphere is about one one-millionth that of the Earth.

But the so-called solar constant is not constant and solar physicists have of late noted changes. ABBOT,[2] speaking of a change of 3½ per cent due to the decrease in solar distance between August and October, adds that "there can be little question that the large changes noted on Mount Wilson are really solar changes and not of atmospheric or accidental origin."

KIMBALL states:[3] "There is evidence that the so-called solar constant is a variable quantity. There is stronger evidence that the atmospheric transmissibility undergoes marked changes that are nearly synchronous over considerable portions of at least a hemisphere, and that diminished transmis-

[1] $1.95 \times 60 \times 24 \times 365\frac{1}{4} \times \pi R^2$, in which $R = 6{,}370{,}191 = 1.3 \times 10^{20}$ gram calories.

[2] *Annals of the Astrophysical Observatory*, page 235.

[3] *Bulletin of Mt. Weather Observatory*, Vol. 3, part 2, page 117, October 19, 1910.

sibility is accompanied by a diminution in temperatures and in temperature amplitudes. Marked diminutions in atmospheric transmissibility occurred in 1884-1886 and 1903 to 1904 that were undoubtedly connected with violent volcanic eruptions. Less marked diminutions occurred in 1891 and 1907 that have not yet been connected with phenomena of this nature."

The question then arises: If on the one hand the solar output varies and on the other the transmissibility of the atmosphere varies according to its dust and vapor content, how are we to differentiate the effects if we make use only of surface temperatures? Accurate measurements of both should be made at widely separated stations. ABBOT, from a comparison of temperatures at many points, concludes that certain abnormal temperature departures at continental stations are recognizable as due to change of solar radiation. At insular stations, however, the temperature departures are less marked.

Temperature abnormalities as shown in annual departures may throw some light upon variations in solar output. For this purpose long series of observations standardized are of unusual value, but one must be on guard for variations caused instrumentally.

Meteorologists are now paying special attention to the so-called permanent pressure areas or centers of action. Possibly future study of variation in location and intensity of these centers may lead to the detection of a relation with solar conditions. But at the present time the outlook is not promising. It may be said that there are at least five well-marked ocean highs in the belts of high pressure and two great lows. The intensity and duration of the great ocean currents are bound up with the position and strength of these centers.

We return, then, to our open fire and as we watch the coals burn, we realize that the processes through which the solar energy became converted into fuel and all the intermediate steps connected with the heating of the atmosphere are yet largely unknown and imperfectly understood. Assuming that a pound of the imprisoned starshine, or lump of fuel, has approximately 14,500 British thermal units, then the equivalent energy would be about eleven million foot pounds or a million

and more calories. But, as we saw at the beginning, this is practically the amount of solar energy which each square centimeter of the Earth would intercept each year, provided the receiving surface was perpendicular to the sunbeam and that there was no atmosphere.

November, 1911.

"RADIAL VELOCITIES OF 150 STARS SOUTH OF DECLINATION —20° DETERMINED BY THE D. O. MILLS EXPEDITION, PERIOD 1903-1906."[1]

By Edwin B. Frost.

This is the most extensive publication of radial velocities of stars which has yet appeared. The three preceding parts of the volume, covering 74 pages, were printed in 1907. They contained a succinct statement as to the organization and history of the D. O. Mills Expedition to the southern hemisphere, by Director Campbell; an introductory account of the expedition, and a valuable description of the instruments and methods employed, by W. H. Wright, who had charge of the expedition. Altogether this volume furnishes an excellent example of the efficient use of a gift of private funds to an existing institution. It is therefore gratifying that the expedition has been continued for two additional periods, first by the donor, and after his death by his son. The success of the work far more than justifies the permanent continuance of this important station in the southern hemisphere, and it is greatly to be hoped that means will be found for maintaining its activity indefinitely.

Attention should be directed to the remarkable economy in the telescopic equipment adopted by Professor Campbell when he first drew up his plans for the expedition about a dozen years ago. Those charged with the plans for useful astronomical apparatus for the new colleges in this country may profit greatly by a study of this simple equipment. A statement of the cost is illuminating: The telescope, of the Cassegrain type, complete, with parabolic mirror of 36 9/16 inches (92.9^{cm})

[1] *Publications of the Lick Observatory,* Volume IX, Part IV. Discussed by W. H. Wright, with the assistance of H. K. Palmer and S. Albrecht, under the direction of W. W. Campbell. 1911. Pages 75-347.